RETHINKING SKETCHING EDUCATION PRACTICES

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ABSTRACT
Sketching is seen as a fundamental element of a design process which allows ambiguity to be maintained and facilitates the perception of new possibilities, re-interpretation and synthesis. Often it is crucial for exploring human aspects of design. At the same time contemporary engineering design education approaches typically do not include sketching explicitly and there are reports of students' reluctance to sketch. To explore this contradiction interviews were conducted with three experienced engineering design professionals, focusing on how they used sketching while designing and compared them to student's sketching practices, identified though sketch output analysis. Results show that sketching is still a part of the design processes of professionals, which is sometimes used in creative ways with computer aided design but is used less habitually in students' work. This paper discusses potential reasons behind this and potential ways to reintroduce sketching to engineering education.

Keywords: Sketching, CAD, education, engineering design, user needs

1 INTRODUCTION
Visualisation of ideas, most frequently via sketching remains recognised as the key design tool during early engineering design stages. These sketches can be digital or paper sketches, but are often quick and hand drawn [1], with provisional decisions and approximate details [2].
Manual sketching is seen by experts to have cognitive benefits that currently cannot be replaced by computational tools [3]. Ambiguity in design sketches is a source of creativity, as it allows reperceiving and reinterpreting of visuals [4]. It allows perception of new possibilities and re-interpretation [5-7] for a **better conception of the design problem** [8] The design restructuring process is difficult to perform using mental imagery alone and can be aided by sketching, although it has been found that experienced designers benefit more from it than novices [9], and sketching rather than use of computers often aids with **the speed of production** [3]. Cognitive chunking has been confirmed via a sketching study, and sketching enables this process of combining multiple smaller information units into larger groups [10], potentially aiding the design process by serving as external memory and overcoming the cognitive limitations of humans [11]. Sketching as a process **does not commit to a solution prematurely** as CAD systems typically lead users to do [12]. Sketching still provides **collaborative working** abilities unrivalled by other modes of idea visualisation, enabling intense shared exploration**,** evaluation and design refinement through the medium [13]. If designers are willing and able to externalise their mental models using sketching, development and negotiation is enhanced[14].
However, the role of sketching and analogue drawing tools in general has been diminished. Use of digital tools, that cannot fully replace sketching [15], has led to manual sketching losing value. Students demonstrate a lack of interest in learning and employing it, and tend to perceive sketching as something they will not use in the future [3]. Engineering students are not sketching as a regular part of their design process [16]. The authors' experiential conclusions are similar, and they have identified either reluctance to sketch or, on average, low sketching capability. It has also been found that students do not understand the role of sketching in the design process, and do not wish to sketch if they perceive their sketching skills are not good enough [16]. A lack of sketching training is a part of the issue, as most engineering design courses are not specifically teaching sketching [17]. Additionally, a variety of inhibitions ranging from trying to make the first attempt perfect, believing that sketching is not relevant to engineering or a perceived or real inability to sketch to a required standard as well as not being in the right state of mind for sketching were identified. While sketch training and inhibition reducing exercises have a positive effect on the use of sketching, they needed to be repeated consistently to achieve a permanent change

[17]. The reluctance to sketch is potentially starting even earlier, as Kelley [18] found that even children in secondary school only sketched when explicitly required to do so.
The purpose of this paper is to explore some of the practical implications of the apparent contradiction between the need for sketching and its lack of presence in a modern engineering design process, by firstly interviewing experienced designers from three different domains, and finding out to what extent, and for what purpose (specifically looking at design problem conception, speed of production, commitment to a solution and collaborative working), they are still sketching. Then we look for evidence of these four aspects of sketching in the work of our mechanical engineering students engaging in a mechanical design project that requires extensive sketching to be completed successfully, allowing us to explore the differences between professional and student practices. We conclude with some recommendations for adaptations of our teaching practices going forward, based on these findings.

2 EXPERIENCED DESIGNERS AND SKETCHING

Semi-structured interviews were conducted with three engineering designers (one architect working in a design and delivery firm, one industrial designer owning a design consultancy focusing on visual communication and consumer products and one mechanical designer working at a product design consultancy focusing on mechanical engineering applications).

2.1 Methodology

Semi-structured interviews were conducted either in person or via Microsoft Teams/Zoom and the structured questions were:

> Did you use to sketch? (2) What do you like about it? (3) Do you still sketch? (4) If so precisely, what do you sketch (and when in the design process)? (5) What is replacing sketching? (6) Can you analyse why that is?

When interesting concepts popped up the interviewers asked for more detail and further explanations. Interviews lasted approximately 45 minutes. Interviews were recorded and transcribed. Two interviewees were male, one female; two were British, one was Italian, they were 46, 40 and 36 years old, with 25, 15, and 10 years of professional experience in their respective field. All interviewees were proficient in the use of CAD tools and sketching, using tools such as Rhino, Solidworks and Revit.

2.2 Interview outcomes

All the interviewees described using sketching as an expedient and often preferred method of communicating in their day-to-day work. Sketching is used at times as a standalone method of communication, at others, to enhance verbal communication and more generally in conjunction with digital media. The form of sketching can take the form of 'conversational sketching,' (in practice an intensely personal process of sharing a piece of paper), or to assist in structuring meetings or presentations to larger groups of people. Sketching was recognised in the interviews, as the core tool in 'story boarding' and depending on the context, could be the preferred medium of persuasion. In discursive situations, sketching is also seen as an effective method of recording.
Sketching was also frequently referred to as a method to assist in synthesising design, described as an expedient method to juxtapose constraints, elements and more generally to scale, which in turn assists in critiquing the design and establishing areas of uncertainty. The process of 'pulling ideas together' by sketching, was described both in a design meeting context to focus collective effort, but also as a tool for self-reflection. One theme that came out in the interviews was that sketching was particularly useful when juxtaposing technical criteria, often generated using complex digital processes, with constraints that are better presented in a qualitative manner. For example, a carefully drawn sketch of a hand interfacing with a device, can add a human dimension to the design problem, and in turn alter the direction of a design discussion.
A recurring theme in the interviews was the technique of 'layering', sketching by hand over an image or a digital drawing. sometimes using point clouds or even combining 3D printed elements withing simple cardboard models. The method at once simplifies the technical aspects of sketching proportionally (effort) and synthesises the design problem.
All the interviewees described instances where they had used sketching to assist in resolving three dimensional spatial problems, rather than or in addition to using CAD software. To a greater or lesser extent, they described using traditional geometric techniques (typically orthogonal projection or two-

point perspective) to test or develop spatial relationships they had formulated in their head. These could be both static and dynamic spatial relationships. One interviewee described this as 'rational sketching' and 'spatial calculation' and another referred to their use of sketches to ' (spatially) test ideas'.
When reflecting on what had changed in the ideation stage of the design process, over their career, all three interviewees presented a complex picture. Whilst to a certain extent they could give examples of senior designers who are reluctant to use certain digital technologies in the early stages of design (including themselves), examples were given of younger colleagues who had a skill, and perhaps a passion for sketching, and continued to sketch extensively. None of the interviewees felt strongly that sketching was disappearing from their design environment or changing significantly, although there was a certain reluctance to be drawn on predicting the future. One interviewee was prepared to speculate that it was about 'augmenting' rather than 'replacing', giving the example of their techniques of combining sketching with Rhino and Grasshopper design software, in the design, to visualise mathematics using a range of geometric tools.

3 STUDENTS AND SKETCHING

Logbooks submitted in support of a final year Mechanical Design project in 2022/2023 and 2023/2024 academic years were analysed, by coding them based on the complexity of sketches, [19] depicted elements, spatial and functional content [7, 20]. The coding output is analysed to match the activities with those identified in the literature.

3.1 Methodology

Coding criteria for the complexity of sketches followed the criteria given in Table 1. Coding criteria for the sketch contents followed the criteria given in Table 2. Both coding criteria have been established in the engineering design field and have largely been followed here with a few adaptations to make the coding process more objective.

Table 1. Complexity codes

Complexity of sketches	Colour	Line and 3D form	Text and numerical annotations	Motion
Level 1	Monochrome line drawing.	No suggestion of 3D form (shading or perspective).	No text annotations are used nor are numerical dimensions.	Motion not indicated
Level 2	More than one colour but unclear what the colour suggests	There is no shading or perspective to suggest a 3D form. Different thicknesses and pressures of line used.	One or two brief annotations may appear not more than 6 or 7 words each.	Motion arrows may indicate moving parts or motion of fluid in a system.
Level 3	More than one colour and meaning of colour indicated	Rough shading or perspective used to give suggestion of form.	The drawing may be annotated to describe certain aspects of the idea (e.g. dimensions)	Motion clearly marked.
Level 4	Colour or gradation may be used, but not to suggest the true colours of parts.	Subtle shading or perspective is heavily suggestive of 3D form.	The drawing will almost certainly be annotated.	Motion clearly marked and has 3D perspective.
Level 5	Colour is used to represent the actual colours of parts of the product.	There is much use of shading. Relative accurate perspective to suggest 3D form.	Annotation will be used to ask questions of the idea or to explain it.	Motion unambiguous.

Some examples of sketches at different levels of complexity, from lower on the left to higher on the right are shown in Figure 1.

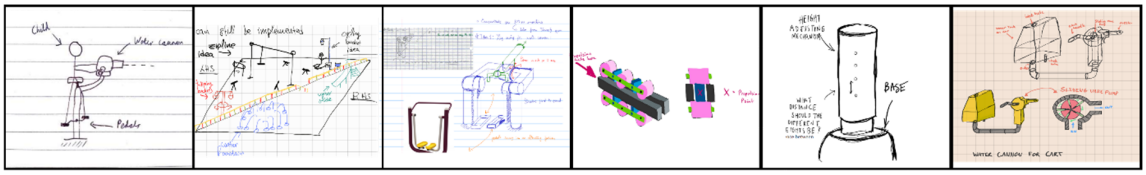

Figure 1. Examples of student sketches with varying levels of complexity

Table 2. Sketch contents codes

Code category	Specific code
Drawing actions	Dc: create a new depiction
	Drf: revise an old depiction
	Dts: trace over the sketch
	Dtd: trace over the sketch on a different sheet
	Dsy: depict a symbol
	Dwo: write words
	Psg: discover a space as a ground
	Posg: discover an old space as a ground
Perceptual actions related to features	Pfn: attend to the feature of a new depiction
	Pof: attend to an old feature of a depiction
	Pfp: discover a new feature of a new depiction
Perceptual actions related to relations	Prn: create or attend to a new relation (non-spatial)
	Prp: discover a spatial or organisational relation
	Por: mention or revisit a relation
Functional actions related to new functions	Fn: associate a new depiction, feature or relation with a new function
	Frei: reinterpretation of a function
	Fnp: conceiving of a new meaning independent of depictions
Functional actions related to revisited functions	Fo: continual or revisited thought of a function

The students are final year Mechanical Engineering and Mechanical Engineering Design students, and their curriculum so far has not included courses on sketching specifically, although sketching was an activity they were encouraged to utilise in their project development in the previous three years. The Mechanical Design class in the final year requires them to submit a logbook showing the research that went into their project and development of their ideas, and it is recommended they utilise visual representation to illustrate their idea development, for example using sketches, but they are not required to do so specifically and there is no predetermined number of sketches that is required.

3.2 Logbook analysis outcomes

In terms of sketch complexity, the picture is consistent over the two years. All individual complexity measures and combined complexity measure are slightly higher in 2023/2024. Use of text to describe the sketches is prominent, often replacing use of colour, line or 3D shapes. On average, all measures are between 1st and 2nd level of complexity, although there were some outliers. Overall, correlation between the number of sketches and their level of complexity does not seem to exist and sketch complexity seems to be dependent largely on an individual's sketching skills.

Sketches are consistently used for depiction (on average 65% of sketches). Looking at development of ideas via sketching (revising an old depiction) there is significantly less activity, on average 35% of sketches. However, for some groups this is as low as 20% and for others as high as 57%, indicating that some groups did use sketching for reinterpretation and conceptualisation of design problems more.

About 50% (range from 29-90%) of the sketches associated functions with depictions, indicating that when the sketches were used for depiction, the depiction included some functional consideration. All groups considered function at some point in their sketches. 5 groups in 2023/2024 went on to reinterpret those functions further in the consequent sketches. This happened to around 3% of sketches on average. This would indicate that only a few aspects that were taken forward were further developed using sketches.

14% of sketches indicated continuous exploration of function through at least one more sketch, following the initial function exploration. However, it was not always the same function being explored

through the sequence of sketches. This is likely due to student background, which is very focused on mechanical features and function rather than conceptual exploration of systemic solutions.
75% of sketches included verbal descriptions, annotations or clarifications of at least some elements. This is likely because the vast majority of sketches were used to visualise a new solution and provide an explanation of their functional capabilities.
Only about 13% of sketches focused on specific features of a new depiction. However almost no sketches were used to discover new features which is interesting given that sketching is widely understood to be used for the discovery of new links and features. It is possible that students, as they are not trained specifically in sketching, do not have sufficient sketching skills to do this kind of exploration. Also, they do not see sketching as a valuable activity, they can reap benefits from. 11% of sketches explored detail of existing, old depictions, developing them further.
All but one group, and 68% of sketches showed evidence of spatial or organisational relation discovery. But they are almost never used to further develop spatial elements (only two groups and 1% of sketches). Looking at the content of the sketches, while the topic of the assignment required extensive consideration of ergonomics and human interaction with mechanisms, there was very limited indications of their consideration in the logbooks.

4 IMPLICATIONS FOR TEACHING ENGINEERING DESIGN

A stark difference is noticeable in how experts and students use sketching to aid their design process, illustrated by Figure 2. While experts have extensively used sketching for conceptualisation of design problems though re-interpretation, students have only partially engaged in this process, in 11-13% of sketches (depending on if old or new features were explored). While professionals tended to use sketches to further explore the concepts prior to committing to a solution, students tended to commit to a solution first and then occasionally use sketching to work out the details of that solution, but not fundamentally change the approach. Speed of production could not be measured in student sketches, as the sketching process was not recorded in terms of time, but the number of sketches could indicate that those that produced more sketches were more efficient in producing them (and some groups were much more productive than others). However, this cannot be established with any certainty. While professionals were very explicit about the use of sketches for collaborative working, there is no clear evidence of collaborative working in student sketches. Even when same sketches are revisited by different groups it appears to be done in isolation, rather than in the context of working in a group.

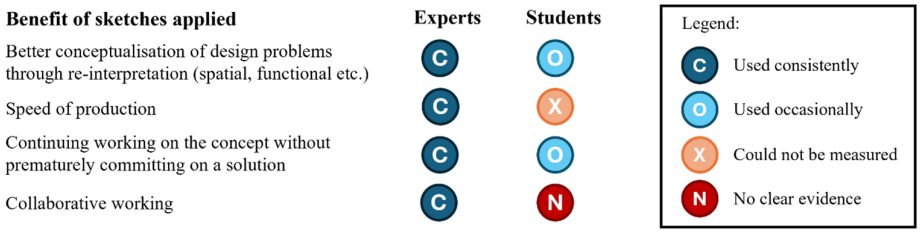

Figure 2. Mapping across benefits of sketching and evidence of its use across the cohort of professionals and students

Formally assessed activities could be added to the programmes to exemplify benefits of and increase use of sketching:

- Sketching activities added to CAD classes in first two years of a degree
- Marked elements of design focused coursework requiring students to reflect on weak elements of their designs via sketching
- Dedicated joint visual groupwork session in latter years of a degree, aimed at developing specific functional or spatial aspects of a design, with reflection on if and what was gained from it. Assessment of what the sketch is communicating and at what level.

The challenge is time commitment. Developing sketching skills takes time and students are not dedicating to it due to lack of perceived benefit. The delivery of a sketching programme could perhaps be in chunks that take up to two weeks of a mechanical design course each year, to aim for better adoption.

5 CONCLUSIONS

While professional designers reported extensive use of sketching across all four observed metrics, mechanical design students showed little evidence of utilising sketching to its full potential. This is to a degree likely influenced by lack of sketch-based activities in their engineering education – there is no dedicated sketching class in the programme and even when sketching is used to aid other learning objectives it is not explicitly marked and thus seen as unimportant by students. Formally assessed taught element of sketching is needed in the mechanical engineering education, ideally focusing on what the sketch is communicating and at what level, as existing mechanical engineering curriculums rarely include sketching activities that exemplify the benefits of sketching in exploring, spatial and functional elements, often key for inclusion of human aspects of engineering.

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